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The US Navy coastal surge and inundation prediction system (CSIPS): Making forecasts easier

Andrew J. Condon[1]
Jay Veeramony[2]

[1] American Society for Engineering Education
Naval Research Lab, Stennis Space Center, MS andrew.condon.ctr@nrlssc.navy.mil
[2] Oceanography Division
Naval Research Lab, Stennis Space Center, MS jay.veeramony@nrlssc.navy.mil

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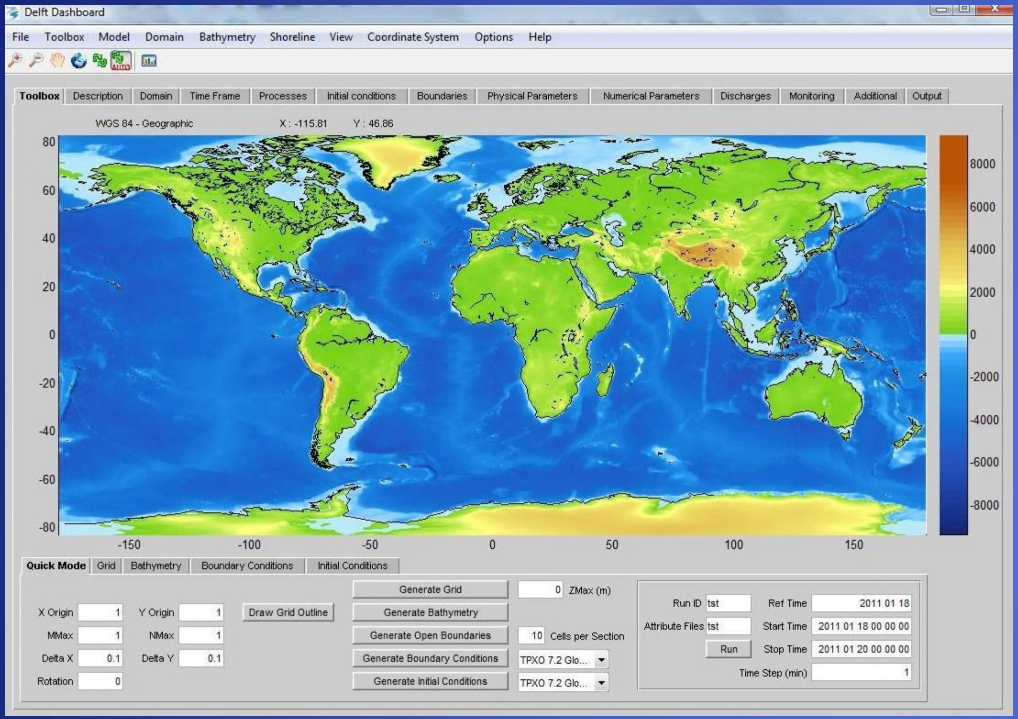
Objective

- To develop a tool (GUI) for storm surge and inundation prediction which results in a minimization in man-hours and required operator knowledge for model set-up as well as result in optimal surge and inundation forecasts
  - GUI – Delft Dashboard with CSIPS toolbox
  - Optimal forecasts – Improved resolution and physics over current system

Coastal Surge and Inundation Prediction System (CSIPS)

- Delft3D - integrated modeling suite, which simulates 2D and 3D flow, sediment transport and morphology, waves, water quality and ecology.
  - Delft3D – FLOW: Hydrodynamic module
  - Delft3D – WAVE : Wave module
- FLOW is dynamically coupled to WAVE by passing water level, currents, winds, and bed level to WAVE and in return gets radiation stresses for wave setup calculations
- Improved physics and resolution over currently used model – PC-Tides
  - Inclusion of wave coupling and large scale circulation

Delft Dashboard



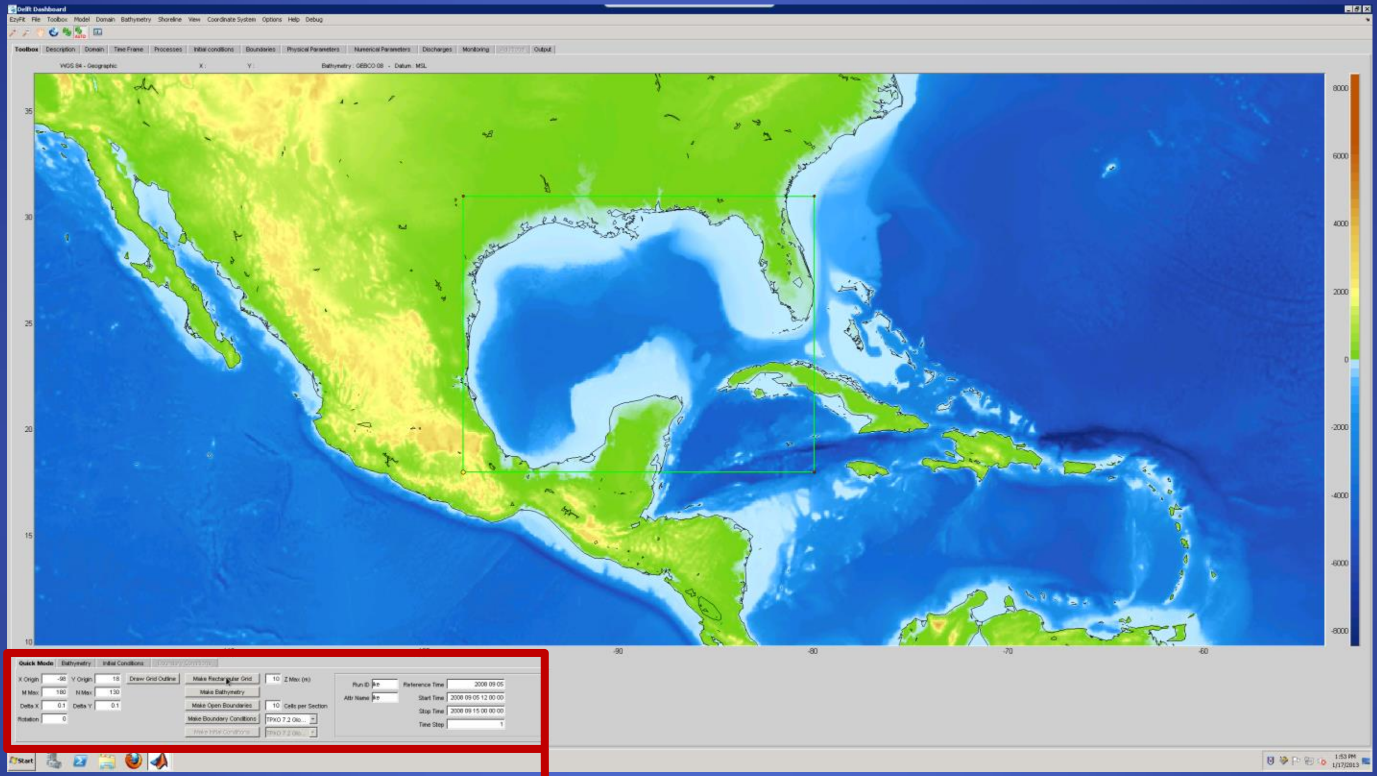
Capabilities from Deltares

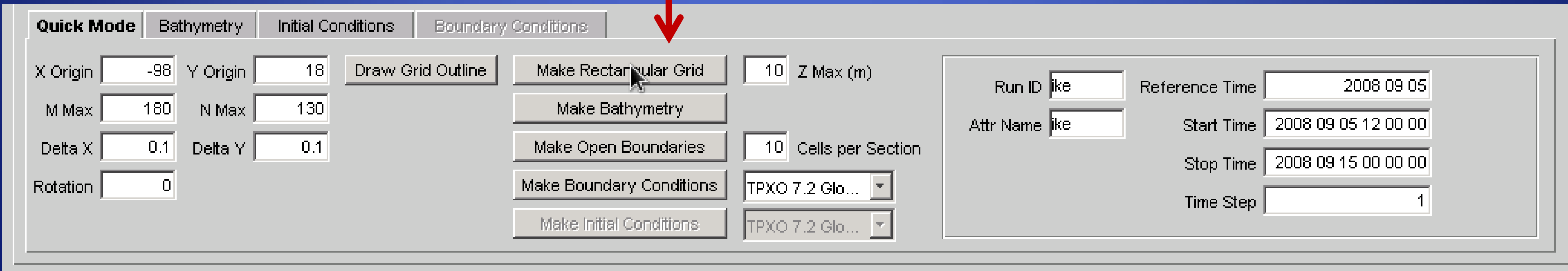
- GUI specific to Delft3D
- Select an area from the world map using the GUI – rectangular grid, size and resolution
- Interpolate bathymetry from dataset
- Specify type of boundary conditions (water level, Riemann, discharge etc)
- Specify type of forcing (Astronomic, time series etc)

New capabilities from Deltares

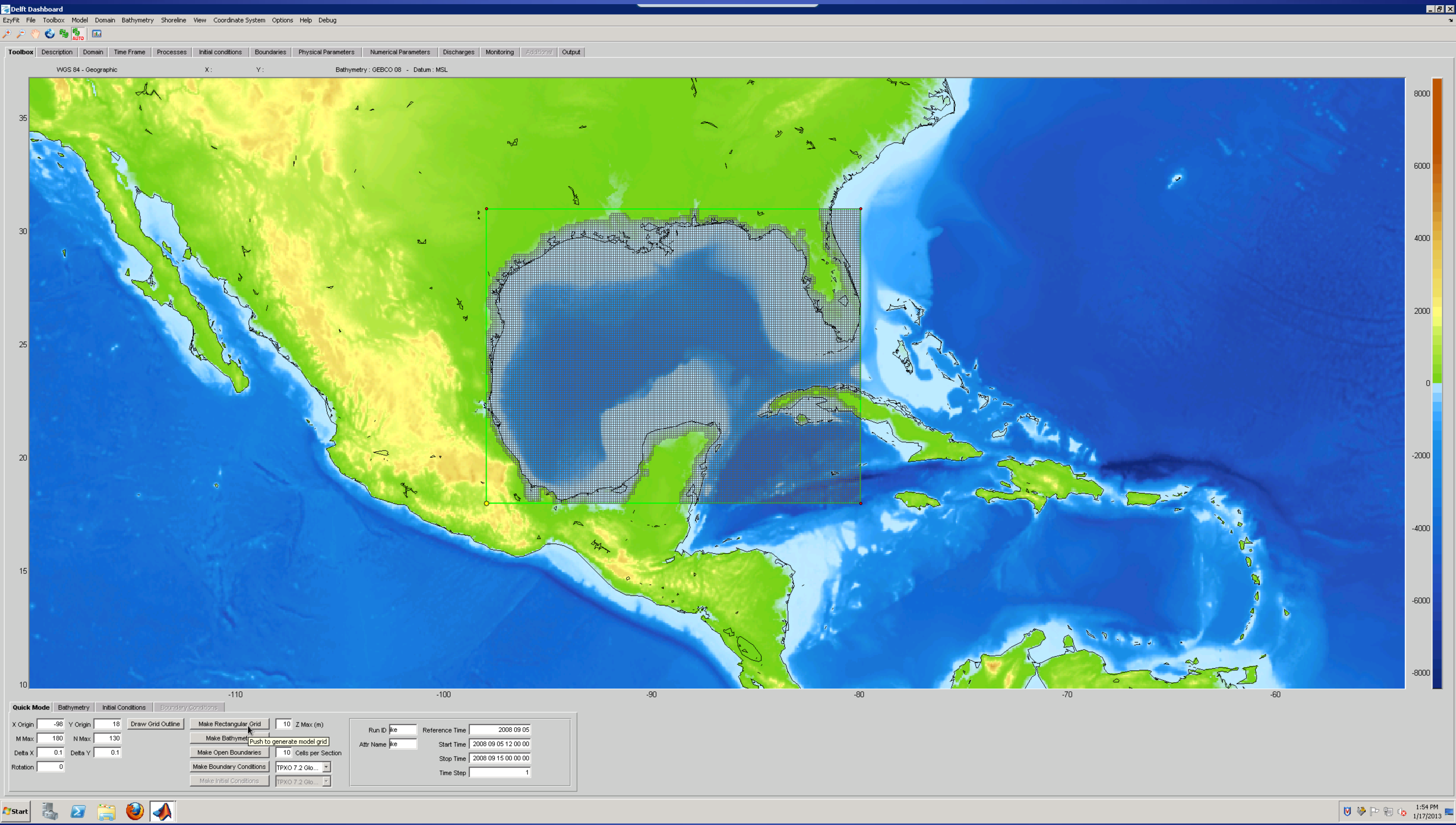
- Extend GUI to include Delft3D-WAVE (delivered, under testing)
- Capability to set up nested domains (delivered, under testing)
- Extension of functionality with outer boundary forcing data from NCOM/HYCOM, COAMPS, WAVEWATCH III (delivered, under testing)

Delft Dashboard - Grid



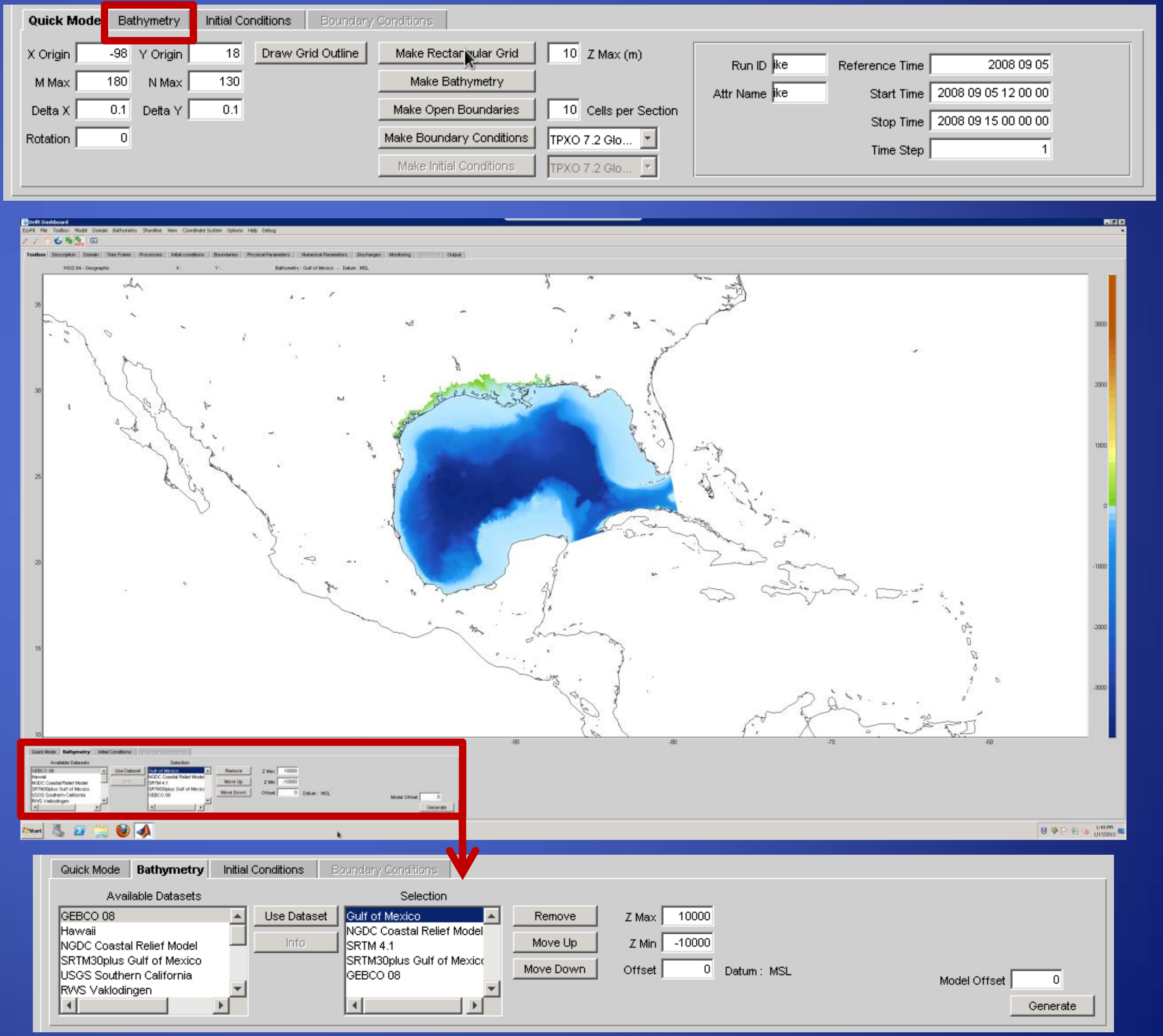


Delft Dashboard - Grid

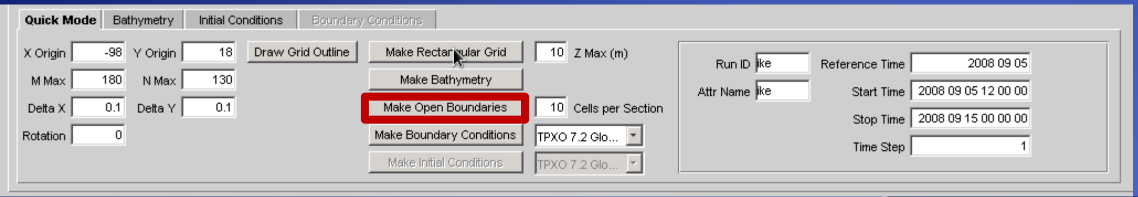


Delft Dashboard - Bathy

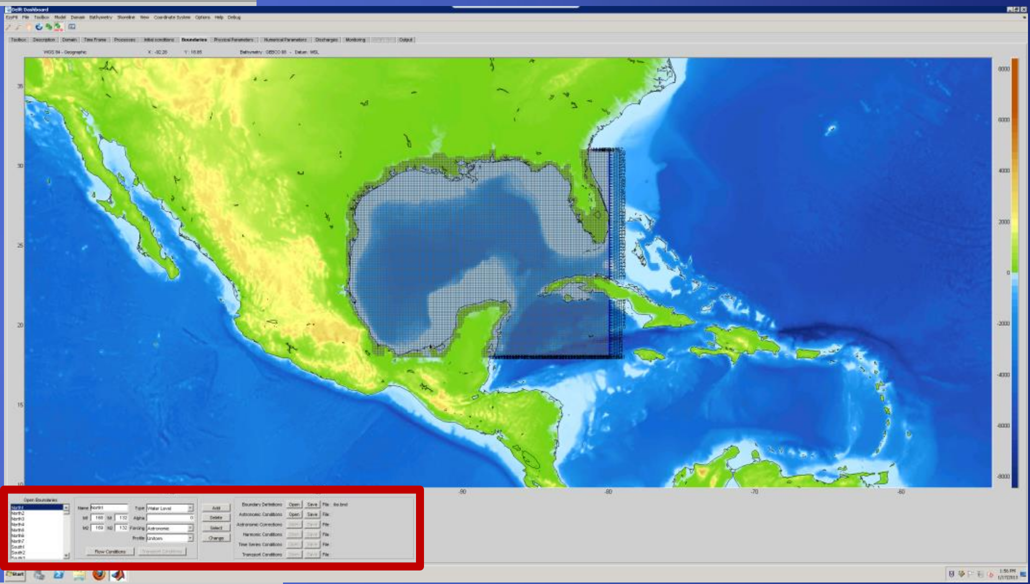
- SURA – Gulf of Mexico
- NGDC Coastal Relief Model
- SRTM 4.1 / 3.0
- GEBCO 08
- USGS California
- RWS Vaklodingen
- EMODnet
- MarineScotland
- GeoScienceAustralia
- NCTR

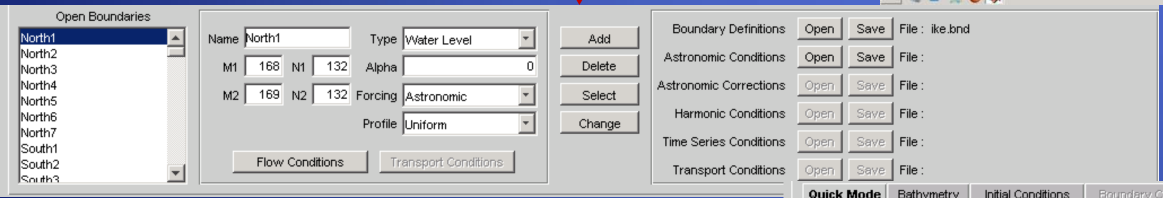


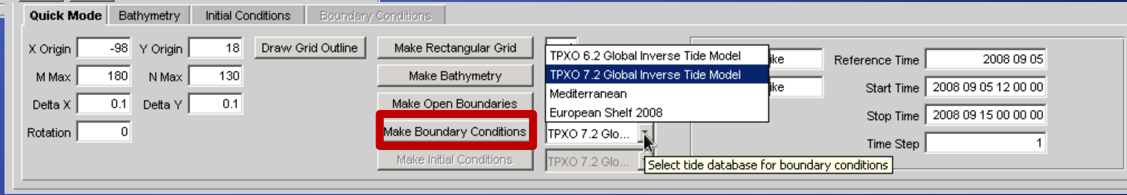
Delft Dashboard – BC's



- Oregon State University Global Model of Ocean Tides
  - TPXO 6.2
  - TPXO 7.2
- Mediterranean
- European Shelf



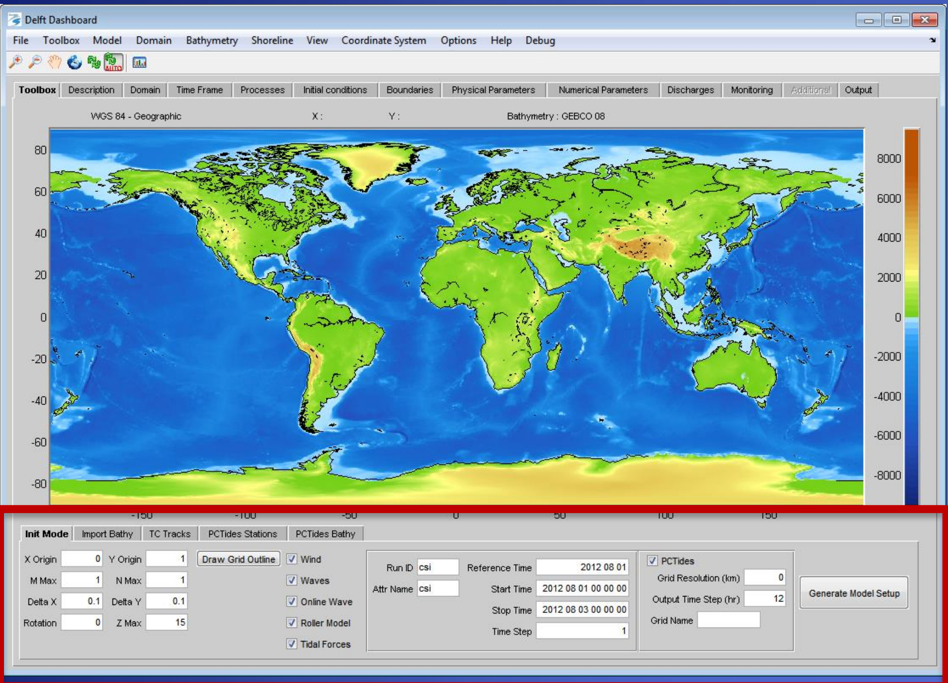


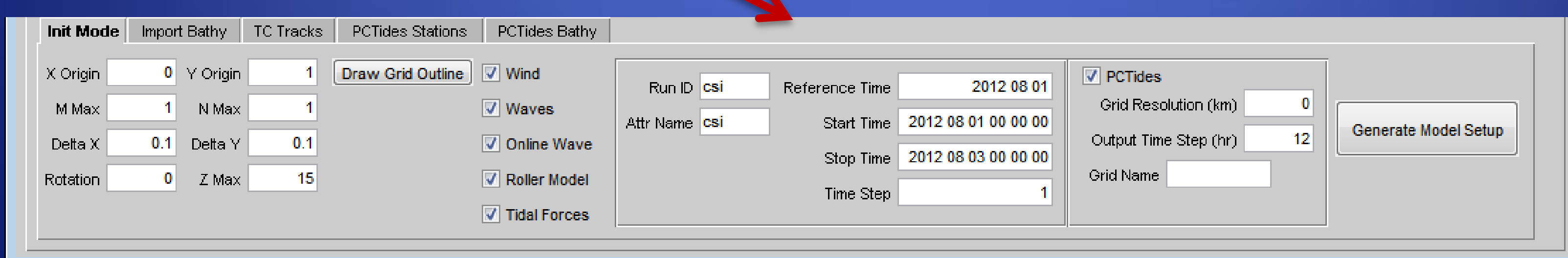


Delft Dashboard – Other Capabilities

- Observation Points / Monitoring
- Physical Parameters
- Numerical Parameters
- Processes
- Initial Conditions
- Discharge
- Output

Delft Dashboard – CSIPS

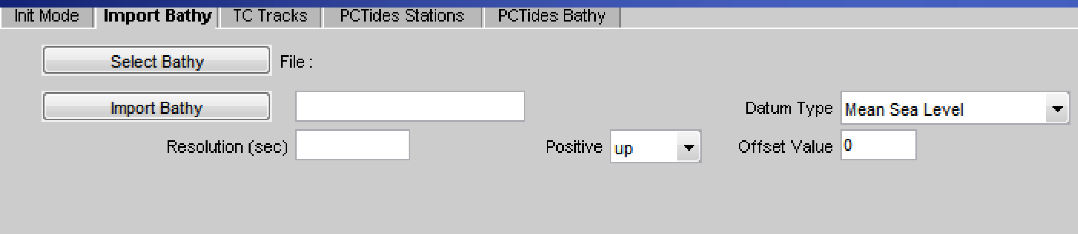




<u>CSIPS TOOLBOX highlights</u>

- Grid parameters: Size, resolution, orientation
  - Option: Draw box for creating grid
- Activate/deactivate processes
- Select forecast start and end time; time step for computations
- PCTides support
  - \+ Model currently used by NAVO
  - \+ Seamless transition (saves setup time and training time)
  - \+ Quick output O(mins)
  - \- Low resolution grids O(km)
  - \- No waves

Delft Dashboard – CSIPS

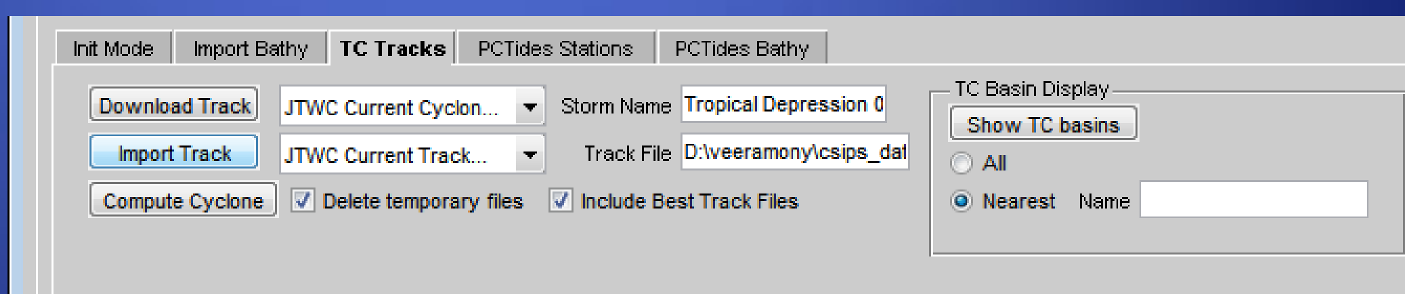


Bathymetry/Topography

- Default: GEBCO 08
- Import feature: Can import xyz/yxz/arc files (standard NAVO format)
  - Convert to tiled netcdf for use in model generation
- Currently supported datums: MSL, MLLW, MHW
  - Can specify offset

TC Tracks

- Full support (D3D, PCTides) for JTWC warning, NHC forecast/advisories, best track files
- Download TC track data on-demand or use locally archived files
  - Time, location checks to avoid mismatches w/model domains

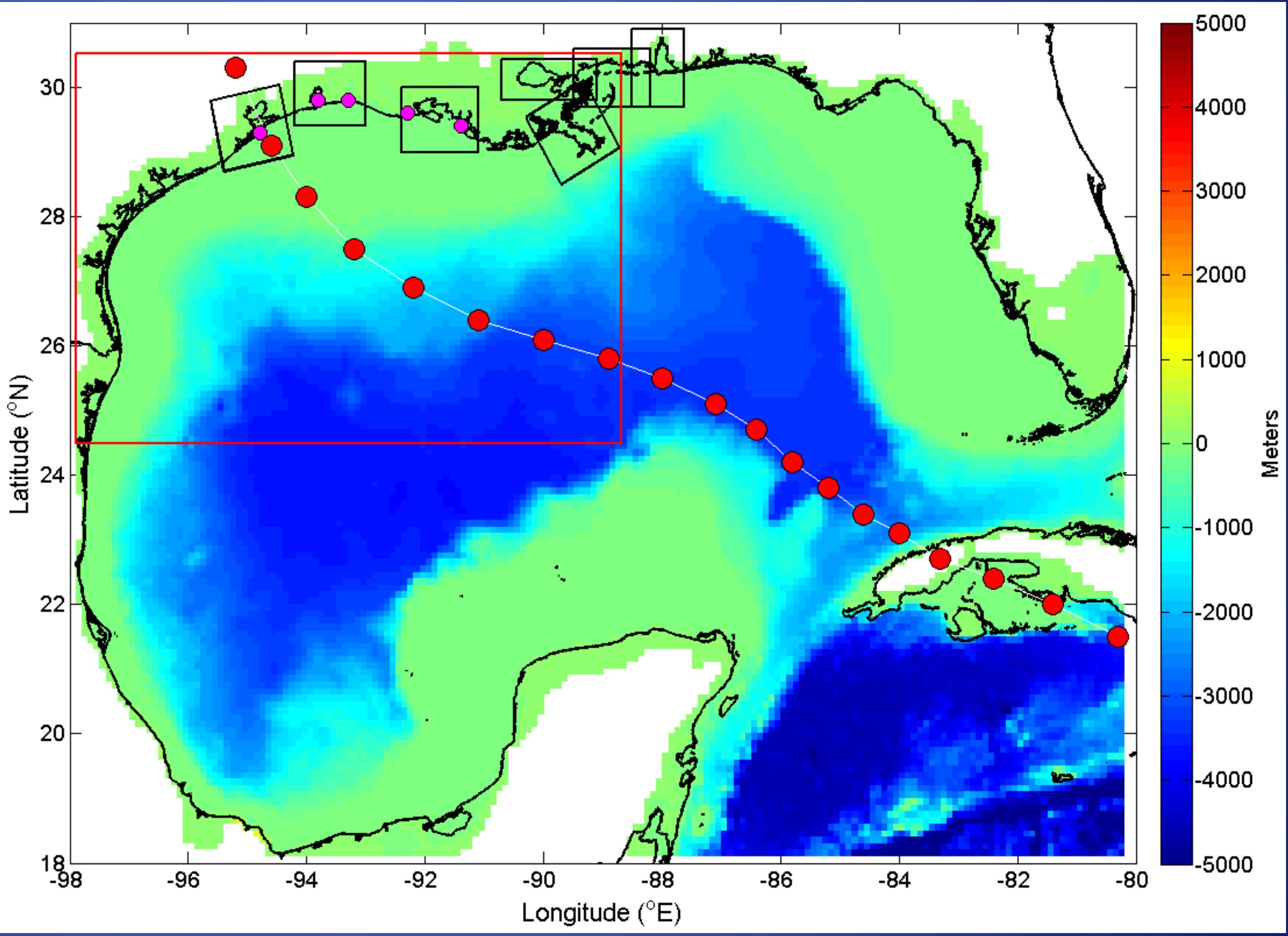


Hurricane Ike

- September 1 – 15, 2008
- Landfall:
  - September 13 0700 UTC
  - North end Galveston Island
  - Strong and large Category 2
  - Highest water mark 5.3 m (17.5 ft.) NAVD88
  - 3rd Costliest storm in US history

Domains

- Gulf of Mexico Domain
  - 0.1° x 0.1°
  - 179 x 129
  - 1 day runtime ~ 30 min @ dt = 10 min
- Nearshore Domain
  - 0.02° x 0.02°
  - 462 x 302
  - 1 day runtime ~ 60 min @ dt = 5 min
- Coastal Domains
  - 0.004° x 0.004°
  - Various sizes
  - 1 day runtime ~ 30 min @ dt = 1 min



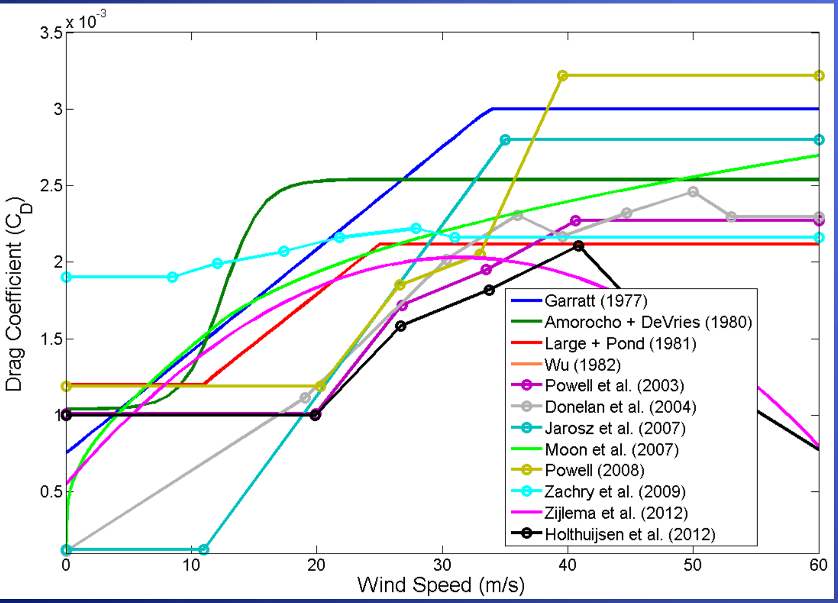
Baseline Simulation
Model Setup

- Gulf of Mexico domain
- Bathymetry / Topography data:
  - SURA inundation testbed GoM dataset
  - NOAA NGDC Coastal Relief Model
  - SRTM topography data
  - GEBCO 08
- Riemann (weakly reflective) boundary conditions with astronomic forcing
- Tidal constituents:
  - OSU global model of ocean tides based on TOPEX7.2 satellite altimeter data
- Initial water level: 0.11 m – seasonal trends
- Wave coupling every 60 minutes

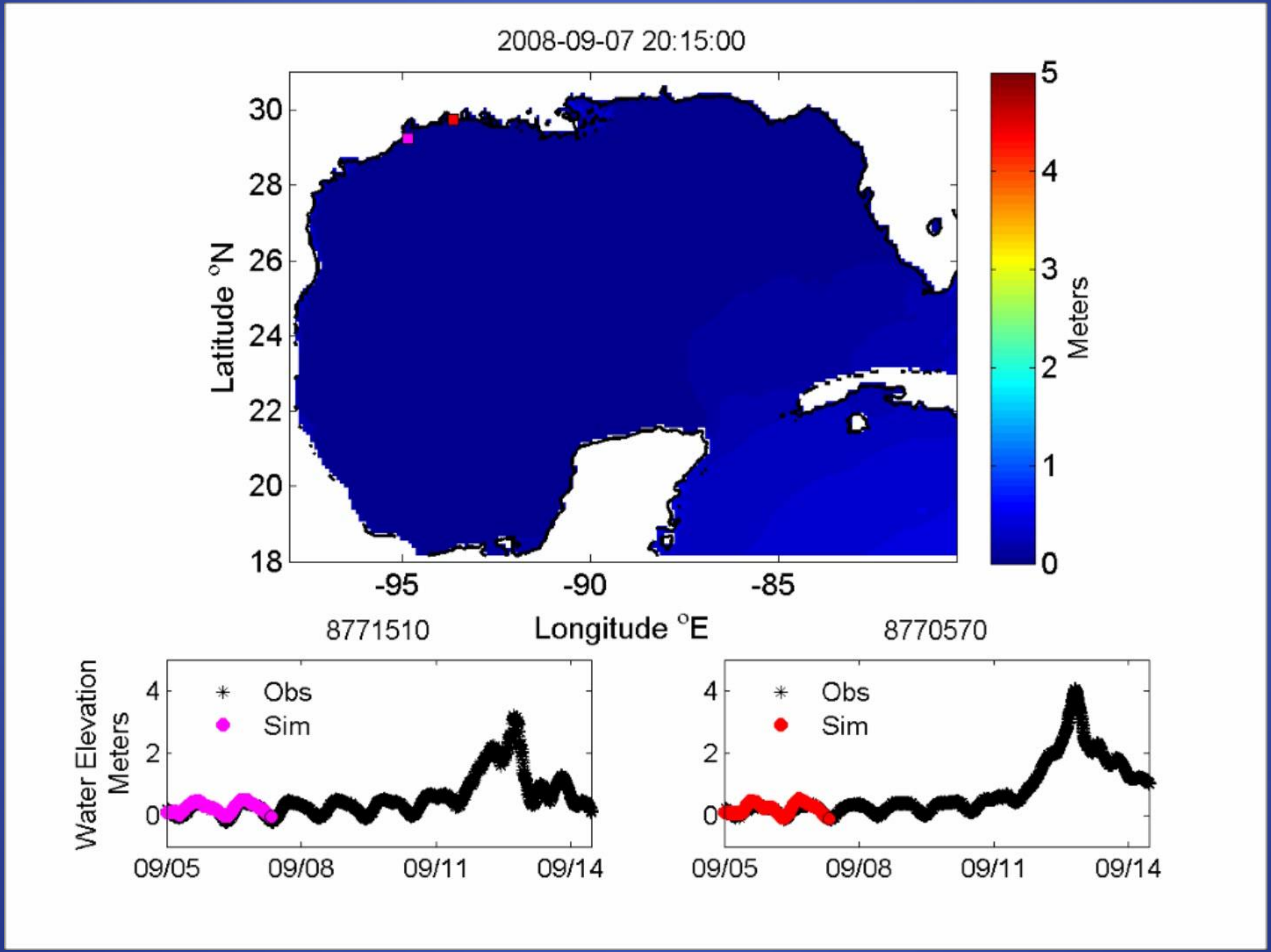
Baseline Simulation
Wind

- Atmospheric forcing provided by Oceanweather Inc.
  - Interactive Objective Kinematic Analysis (IOKA)
    - Hwind blended and local measurements are blended with large scale wind and pressure field
- Considered 12 drag coefficient formulations
- Formulation of Holthuijsen et al. (2012) produced the best results

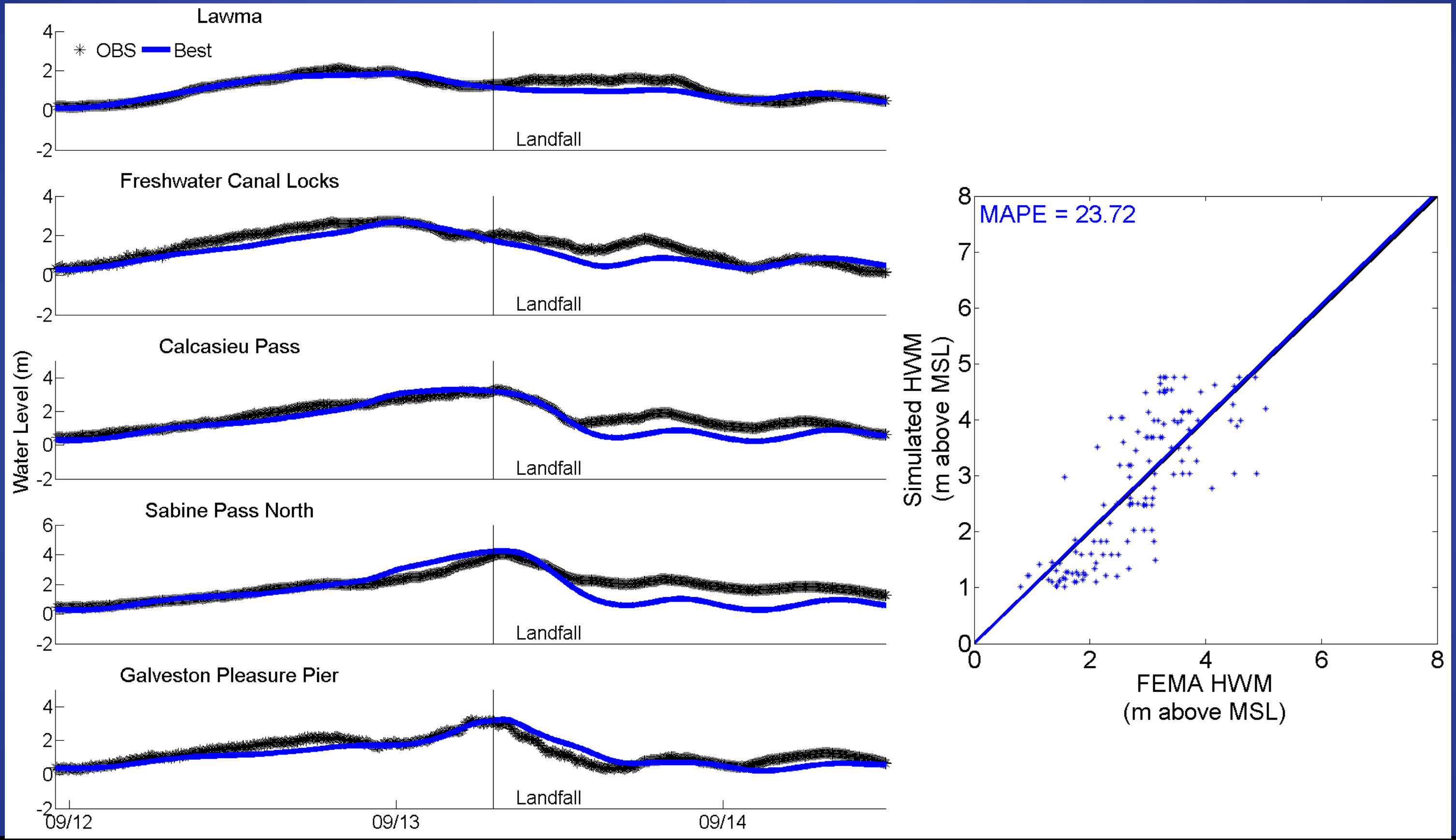
Peak Water Level Percent Error					
C_D Formulation	LAWMA, Amerada Pass	Freshwater Canal Locks	Calcasieu Pass	Sabine Pass North	Galveston Pleasure Pier
Garratt (1977)	5.48	17.12	20.26	25.79	15.97
Amorocho and DeVries (1980)	7.12	15.42	17.80	22.56	12.93
Large and Pond (1981)	-1.62	8.19	9.23	13.13	6.80
Wu (1982)	5.70	18.01	20.60	26.38	16.72
Powell et al. (2003)	-10.35	2.36	3.15	6.94	3.62
Donelan et al. (2004)	-6.63	4.70	5.85	9.89	5.52
Jarosz et al. (2007)	-8.13	7.73	10.01	14.93	9.45
Moon et al. (2007)	-0.02	9.82	11.04	15.38	8.65
Powell (2008)	-7.81	5.70	6.69	11.33	7.57
Zachry et al. (2009)	1.13	9.35	11.33	15.49	8.30
Zijlema et al. (2012)	-2.17	6.98	7.74	11.47	5.62
Holthuijsen et al. (2012)	-12.34	-0.59	0.78	4.49	1.72



Baseline Simulation Results

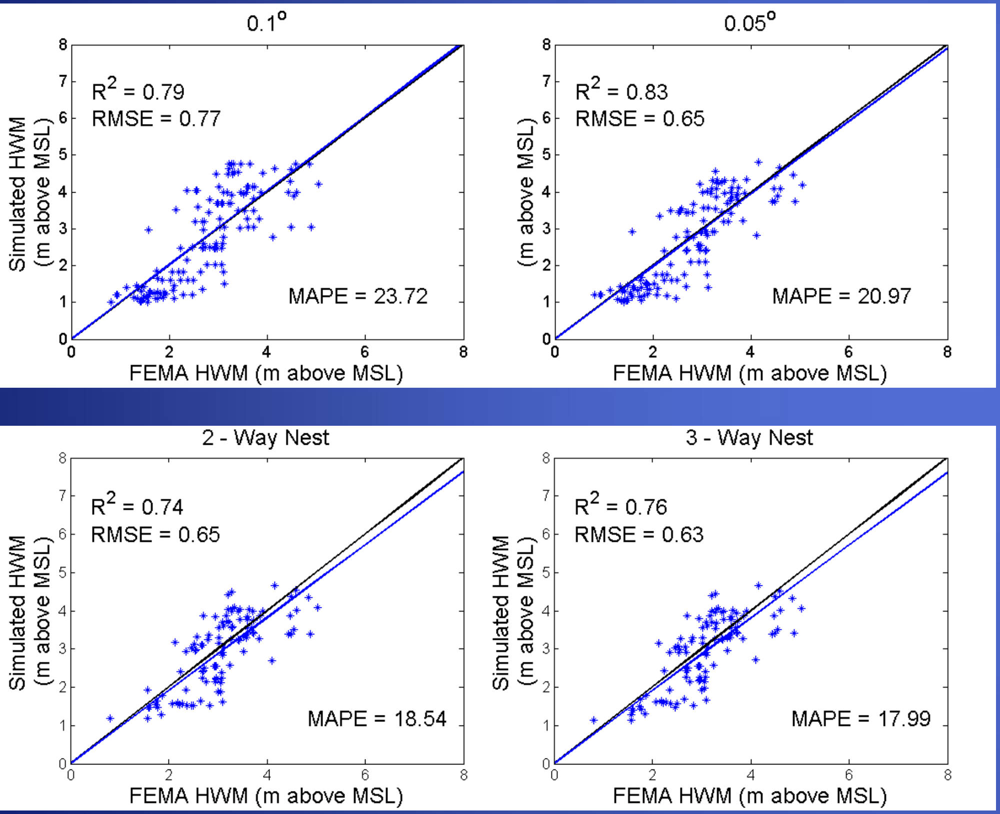


Baseline Simulation Results



Peak Water Level Percent Error					
LAWMA, Amerada Pass	Freshwater Canal Locks	Calcasieu Pass	Sabine Pass North	Galveston Pleasure Pier	High Water Marks
-12.34	-0.59	0.78	4.49	1.72	23.72

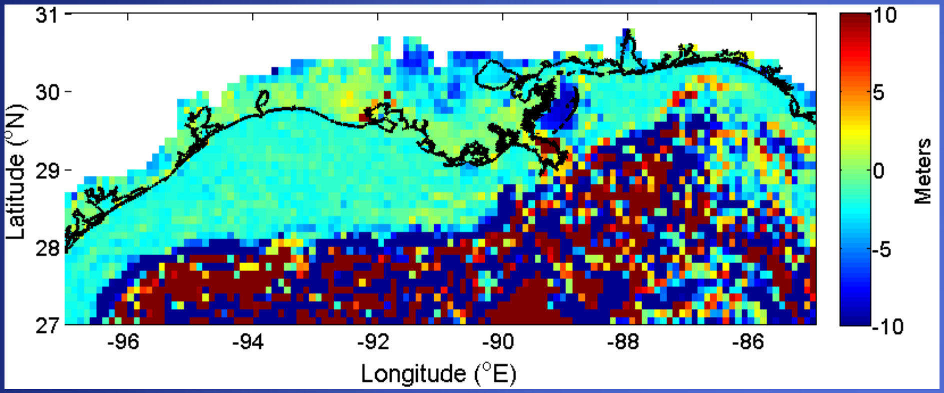
Sensitivity Studies
Grid Resolution



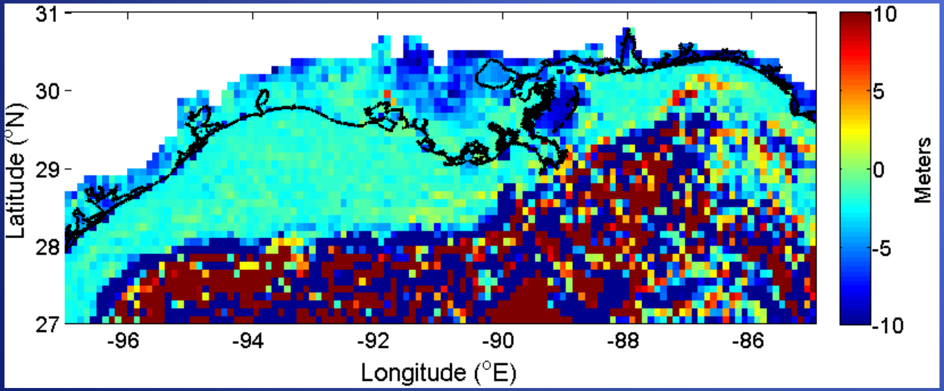
- Water level results good with coarse resolution
- Inundation results improve with increasing resolution
- 0.5° domain
- 2 – way nesting
  - 0.1° to 0.004°
- 3 – way nesting
  - 0.1° to 0.02° to 0.004°

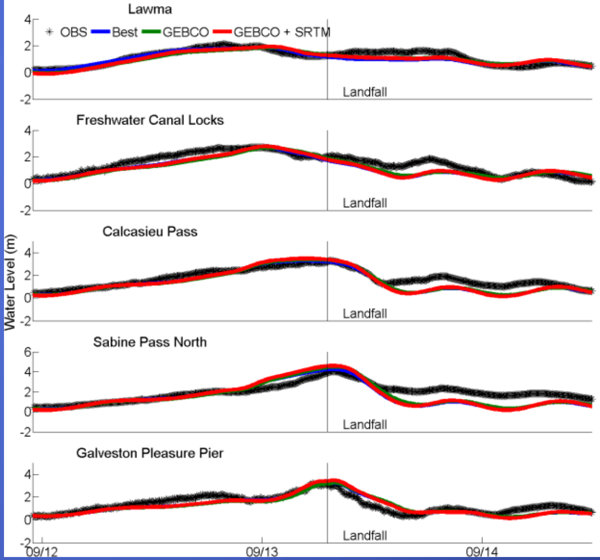
Sensitivity Studies
Bathymetry / Topography

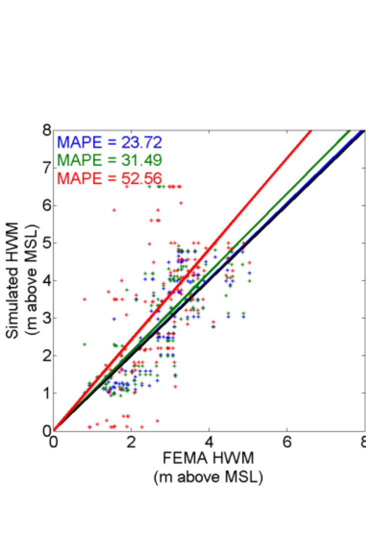
Baseline - GEBCO



Baseline – GEBCO+SRTM

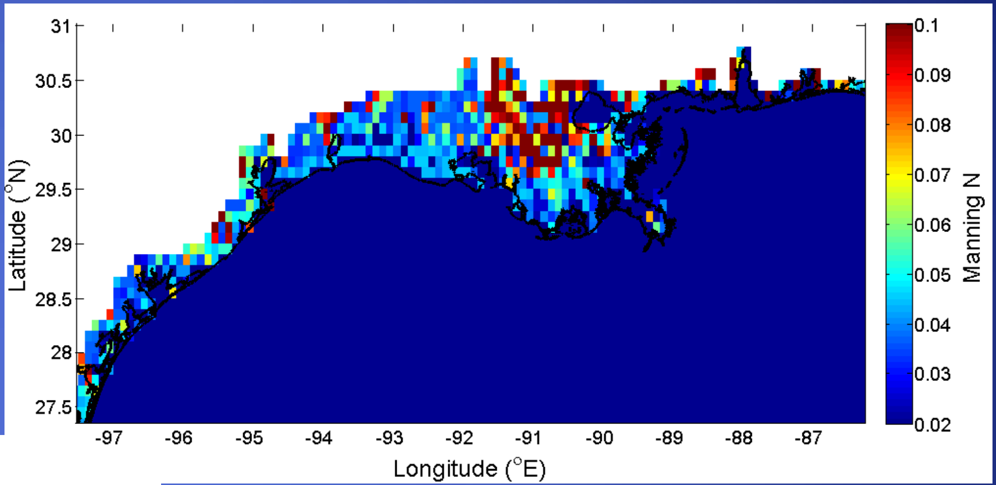


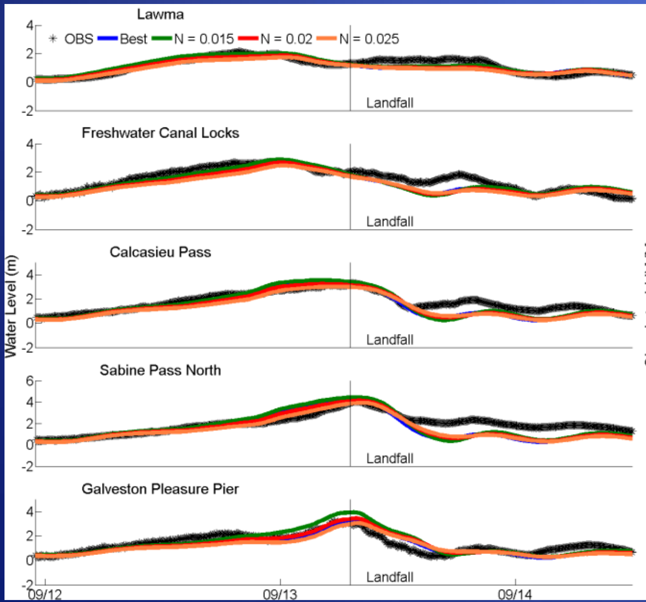


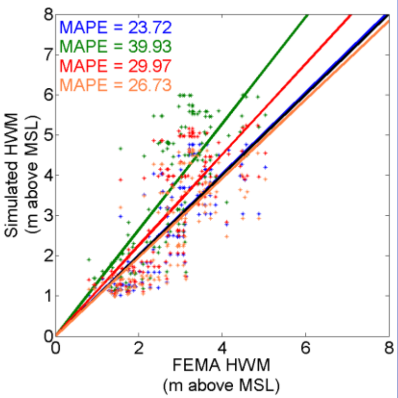


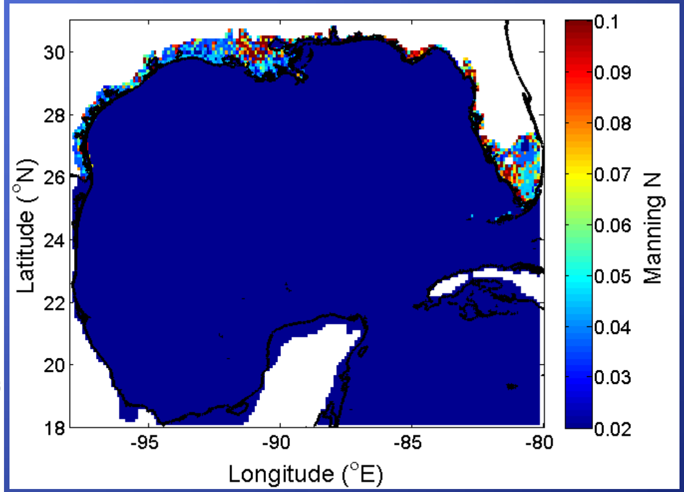
Sensitivity Studies
Bottom Roughness

- Variable Manning's N coefficient based on land use data
- Offshore value of 0.02









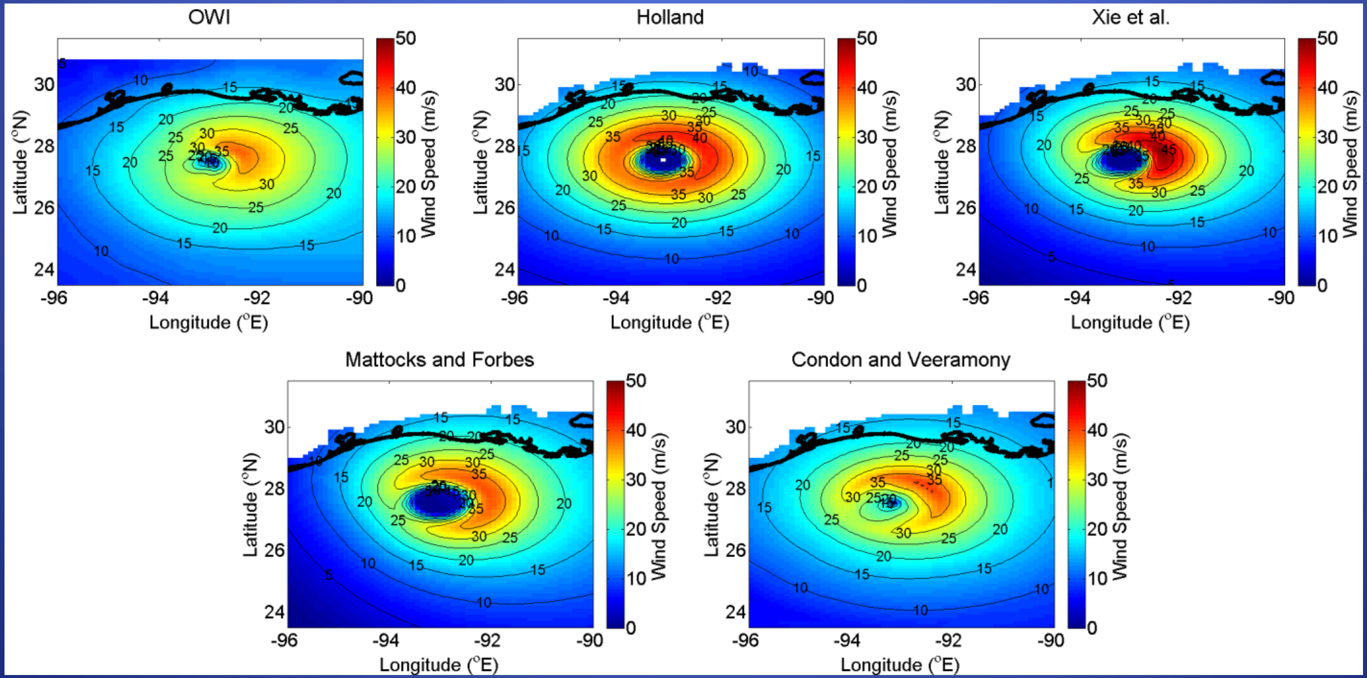
Sensitivity Studies
Waves

- Wave coupling defined by communication time between FLOW and WAVE modules

Run	Water Level – Percent Error of Peak					HWM MAPE
	Lawma, Armeda Pass	Freshwater Canal Locks	Calcasieu Pass	Sabine Pass North	Galveston Pleasure Pier	
Baseline (60 Min Coupling)	12.34	0.59	0.79	4.49	1.72	23.72
No Waves	48.77	46.25	37.33	32.76	25.81	32.94
20 Min Coupling	9.00	4.06	3.55	4.50	3.43	23.37
30 Min Coupling	8.98	4.04	0.52	4.36	1.40	23.97
120 Min Coupling	13.86	5.09	3.27	6.51	3.25	23.92
180 Min Coupling	10.67	3.69	2.67	6.66	2.51	23.89
360 Min Coupling	16.06	15.69	3.33	4.44	0.74	22.93

Wind Model

- Tested four analytic models using NHC Best Track data
  - Holland (1980)
  - Xie et al. (2006)
  - Mattocks and Forbes (2008)
  - Condon and Veeramony



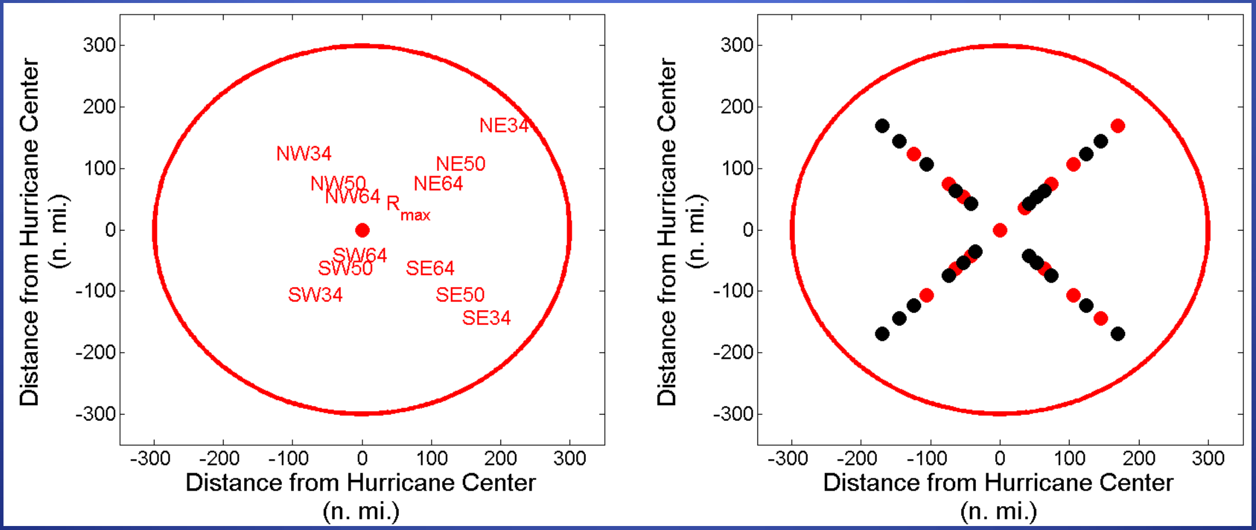
Wind Model
Condon and Veeramony

Example: W_s = 95 KT, R_{max} = 50 n. mi., P_n= 1007 hPa, P_c = 954 hPa, R_O = 300 n. mi.

64 KT…	105NE	90SE	60SW	75NW
50 KT…	150NE	150SE	90SW	105NW
34 KT…	240NE	205SE	150SW	175NW

$$V(r) = \left[\frac{B}{\rho_a}\left(\frac{R_{max}}{r}\right)^B (P_n - P_c)\exp^{-(R_{max}/r)^B} + \left(\frac{rf}{2}\right)^2\right]^{1/2} - \left(\frac{rf}{2}\right)$$

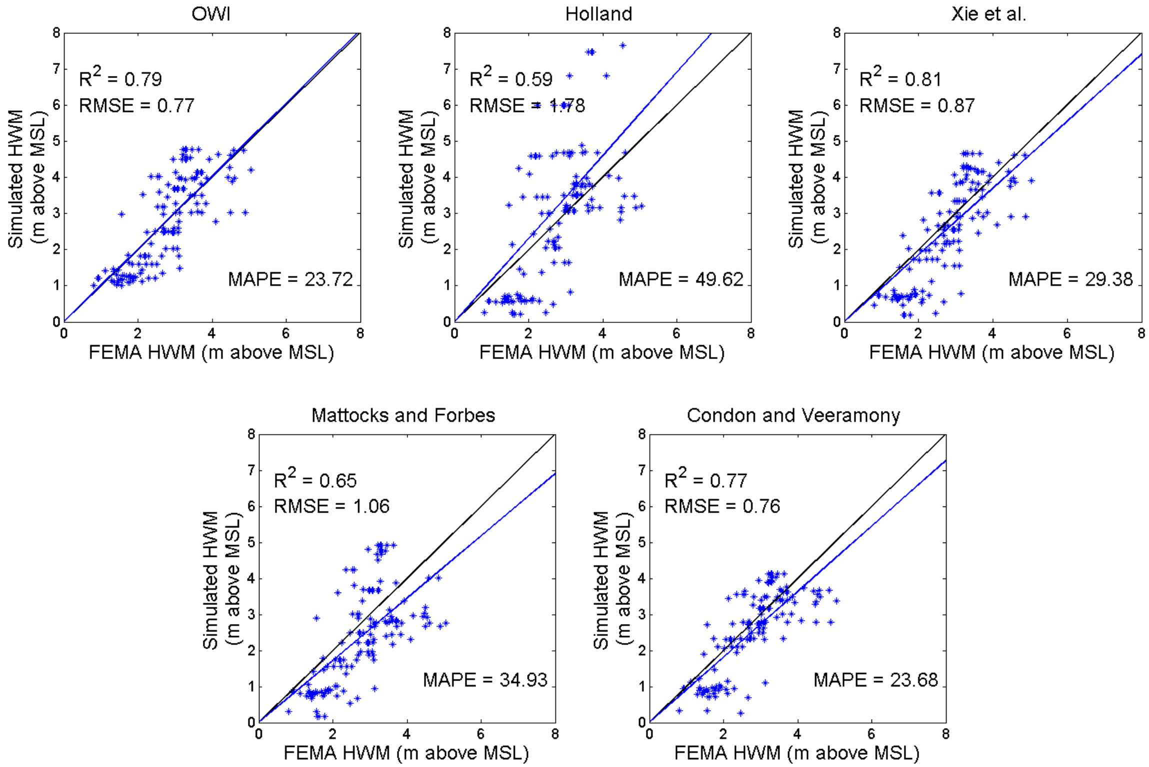
$$B = \frac{(V_R^2 + V_R R f)\rho_a e}{P_n - P_c}$$



Wind Model Results

Wind Speed (m/s)	H80	X06	MF07	CV12
0 – 10	3	2	1	4
10 – 20	1	2	3	4
20 – 30	2	1	3	4
30 – 40	1	3	2	4
40 – 50	1	2	3	4
Total	8	10	12	20

Ranking based on comparison to Hwind of the Integrated Kinetic Energy – by wind speed band



Conclusions

- Delft Dashboard coupled with the CSIPS toolbox provides the framework to create and run storm surge and inundation forecasts
- As expected the model results are very sensitive to a number of input parameters (You need good data!)
  - Proper grid resolution is necessary for quality inundation results, can get by with coarse resolution to model coastal water levels
  - Bathymetry / Topography data matter – High resolution data can have a large influence even on a coarse grid
  - Land cover / bottom roughness data is needed to improve inundation simulation results
- Proper wind forcing is needed
  - Many modeling studies use older drag formulations with a simple cap; newer formulations may offer better results
  - Various analytic wind models can offer very different results
  - New model offers promising results … more testing is needed

Ongoing Work

- Validation with Hurricane Irene and Typhoon Pongsona
- Including new wind model in Dashboard framework
- Spatially variable resolution grid generation in Dashboard – test vs. nesting
- Streamline everything for operational use
  - Testing to begin this coming hurricane season

Thank you

Questions?

Contact: andrew.condon.ctr@nrlssc.navy.mil

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- Delft3D – FLOW: solves the shallow water equations with a finite difference scheme in 2 (depth averaged) or 3 dimensions. It computes the non-steady flow resulting from tidal forcing along the open boundaries, wind stress and atmospheric pressure along the free surface, and forcing from pressure (barotropic) or density (baroclinic) gradients
- Delft3D – WAVE: Based on the third generation wave model, SWAN, it computes the full wave spectrum by considering a number of processes including: wave refraction; generation by wind; depth and current induced shoaling; dissipation due to whitecapping, bottom friction, and breaking; nonlinear interactions; transmission and blocking by flow and obstacles; and diffraction

Sensitivity Studies
Boundary Forcing / Water Level

- Initial water level ~ 0.11 m
- Constant boundary forcing (A0) of 0.055 m along with tides
- TPXO 7.2 vs. TPXO 6.2